The Characterisation and Removal of Water Droplets in High Pressure Water Jetting Nuclear Decontamination (16036)

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ABSTRACT
The use of high pressure water jetting as a decontamination method has seen limited deployment within decommissioning operations in the UK. The full extent of secondary waste forms produced as a result of such operation has not been previously investigated. The aim of this investigation was to determine the process of water droplet formation within the decontamination area and subsequent air treatment pathway. Evaluating the potential security hazards associated with the most widely implemented air filters used as a radiological protection barrier.

INTRODUCTION
The United Kingdom (UK) has seen the use of nuclear materials for military purposes and civil energy generation since the 1940's. The development of such technologies has led to the expansion of related infrastructure, catering for the industrial needs of nuclear energy generation and weapons development. Consequently, the initial development programs and commercial ventures that were conducted have become obsolete. This created a need for such installations to be removed, meaning they must undergo decommissioning operations (1). The nuclear decommissioning authority (NDA) is a government organisation responsible for managing all nuclear decommissioning operations within the UK, this is inclusive of all reactor sites, research facilities, fuel processing plants and the largest and most complex decommissioning site in the UK Sellafield. The main responsibilities of the NDA are focused around ensuring waste materials are removed responsibly and safely, implementing waste storage policies from the UK government in both short and long term strategies and ensuring decommissioning strategies of current operating power stations are adequate (2). This requirement is related to the need for environmental security of all artificially produced radionuclides and be handled in a responsible manner (3). To ensure this material must be disposed of or stored in facilities designed for such a purpose. The initial infrastructure developed for the UK's nuclear endeavour was not fitted with sufficient longevity for interim storage of materials nor was it constructed with specific infrastructure to cope with the need that are required for decommissioning operations to be undertaken successfully. This poses further difficulties for those tasked with conducting the decommissioning operations as all operations required a bespoke approach taking into account a multitude of radioactive wastes and facility designs (4).

Nuclear Decontamination

Decontamination operations at nuclear facilities are conducted with the final aim of returning the site back to an unlicensed area or into a condition where further nuclear operations can be conducted. These operations fall into three defined steps consisting of (5):

1) Radiation decontamination, this process involves the reduction of the activity levels of radiation detectable within facilities. This is achieved by reducing the concentrations of radionuclides that are contained within the sites facilities. Such processes can be conducted using maned operations or by remote handling, this is entirely dependent upon radiation levels present.

2) Waste removal, once radioactive material has been removed it is necessary for a final disposal route to be selected. This step is subject to the activity levels of the removed waste, as this will determine which disposal route the material will take. The desired disposal facility in the UK for higher activity waste forms is a geological disposal facility for permanent disposal and storage of radioactive waste.

3) Demolition of site infrastructure is the final step of the decommissioning phase for a site. The decontaminated facilities are finally removed and the site can be given over to further nuclear operations or released from operational control.

It is necessary for these decontamination operations that are conducted within the nuclear industry to have in place robust environmental protection barriers, maintaining containment of radioactive waste must be ensured indefinitely (3). Simply leaving existing infrastructure to cope with such a task is not deemed an adequate strategy by industry regulators. The key aim of the three stages is to remove radioactive wastes and dispose of them in the appropriate waste stream. The waste stream is characterised by the total radioactivity levels present within the waste form. Waste can be classified into low level, intermediate and high level waste (6). The aim of the decommissioning process is to remove wastes and place them within the appropriate waste category. The use of decontamination techniques is to minimise the quantities of active waste by separating contaminated materials from those that contain no active radioisotopes, this process reduces the volume of waste by concentrating the more highly active material (2). This project focuses upon the decontamination phase of operations and the effect that these may pose on the containment of radionuclides.

Radiological decontamination is the process of removing radioactive isotopes which may be present as a solid mass such as a spent fuel rod, a radiological deposit materials formed on a material exposed to a radioactive source or a contaminated liquid effluent which has come into contact with radiologically active material (7). There a number of methods currently available to operators that can be implemented to achieve radiation removal:

1) Mechanical decontamination, harnesses physical processes such as scrubbing, scrabbling and washing of surfaces that contain detectable radiation.

2) Chemical treatments consist of chemical agents forming complex molecules removing chemicals from target materials or the use of strong acids/alkalis that dissolve the surface contamination.
3) Emerging technologies, new developments in the field of decontamination have seen the rise of systems that harness the use of lasers and ultrasonic instruments that have the potential to remove radionuclide contaminates. There are also biological methods under development for wide scale radionuclide removal.
4) Mettle melting, the removal of metallic material from facilities to undergo smelting reduces the volume of the total waste form and can also reduce contaminate levels within the slag produced if an oxidising agent is applied within the process.

Utilising the above techniques decontamination operations may be successfully undertaken upon contaminated targets (5). The majority of contamination is treated by removing the surface layer of deposited radiation from materials such as concrete and steel. However, depending upon the depth of contamination present part or all of the material may require removal or disposal. To achieve the desired reduction in activity operators must select the most appropriate decontamination technique available (7). There are a number of factors determining which methods can be successfully implemented: size of target area, accessibility to the contamination and level of radiation activity present. The main limitation upon the decontamination method present is the radiation dose an operator will receive if they are conducting operations within the area as workers are subject to strict radiation dose limits (8).

The primary aim of the decontamination phase of decommissioning operations is to reduce the activity level of the contamination present, in order to dispose of waste forms in a lower waste category disposal facility or allow for the reuse of the component or facility (9). This is a critical step with regards to the viability of a final waste disposal strategy as the lower the final volumes of high and intermediate level waste in existence the smaller the overall cost of disposal. This is due to the UK’s proposed final disposal options consisting of a proposed geological disposal facility for the intermediate and high level wastes, this options will prove costly making appropriate decontamination methods critical, however the lower the volume of waste the smaller this facility can be in order to meet the needs of the UK (2).

The key concern to those conducting decontamination operations where radiation is present is the need for the activities to be segregated from the open environment. This required the implementation of protection barriers in order to prevent the exposure of radionuclides to the environment (10). Such precautions mean that facilities conducting decontamination must be equipped with suitable engineered barriers to prevent the escape of radionuclides associated with operations. A containment breech could potentially lead to severe legal penalties against operators. Radiation releases can occur during numerous phases of the decommissioning process, primary waste forms being released into the environment is a direct contamination pathway, whereas decontamination operations can lead to a produced secondary waste form being released during the treatment process. Secondary waste forms area more likely to lead to a contamination event as facilities containment barriers may not have been designed for the phase in which such waste is present. It is imperative that methods of decontamination are thoroughly investigated before implementation in order to avoid environmental exposure via transport mechanisms that otherwise might not have been foreseen. Mechanical and chemical decontamination methods typically produce a variety of secondary waste forms in which can be present in a variety of physical states. With this in mind all decontamination methods require bespoke approach in order to ensure the protection measures implemented are suitable (11).

High Pressure Water Jetting Surface Treatment

The study focused on the implementation of high pressure water jetting as a method of mechanical decontamination, as a removal technique for radionuclide contaminated surfaces and materials. The process relies on the impaction of water droplets upon the target surface in order to remove the radioactive material present on the surface and as a consequence this may also removes the upmost layer of object being contaminated (12). This process leads to the creation of secondary wastes making the implementation of mechanical water jetting decontamination difficult for large scale operations. This is due to the need to contain the secondary wastes that are produced as well as the initial waste forms undergoing decontamination. The secondary wastes identified within this process are mainly particulates of radioactive materials present as aerosols or small water droplets produced from the high velocity impaction of the water jet. These droplets are present in high concentrations and contain various amounts of material from the targeted media. Larger amounts of contaminated material can also be produced during the process depending upon the target media and the force of the water jet implemented (13). The droplets and aerosols become suspended in the decontamination chamber atmosphere, where they can be extremely mobile or undergo settling (14). The particles are free to move within the confinements of the operational area and into any air treatment system that may be in use. The particles can contain the detached radionuclides from the target object which makes them a concern to operators as they are free to contaminate those conducting the operations and the decontamination area itself (13). To counteract the dispersal extent of such particles the decontamination facilities are operated at a negative pressure, this is achieved by drawing the atmosphere from within the chambers through a ventilation system where the produced contaminates can be removed by subsequent filtration systems (15). However, the largest volume of secondary waste produced by high pressure water jetting is the liquid effluent, from the jetting activities which contains the detached material. Due to this the effluent contains radioactive material, requiring specialised chemical separation in another waste stream. Once the contaminate build within the effluent has exceeded expectable radiation dose limits it must be removed from the decontamination chamber (8). In order to limit the volumes of effluent produced by the water jetting systems, operators implement a process of water recirculation through the jet pump to limit the volumes of effluent that require chemical treatment. This recirculation however inevitably causes the components of the jetting equipment that come into contact with the recirculated water causing the components to become contaminated with radionuclides. This limits the operational versatility of the jetting equipment has once contaminated it can only be implemented within the facility conducting the specific operation and must be fully decontaminated itself before removal (16).

There is a large probability of radionuclides breeching the containment barriers with a process such as this however this is dependent on the robustness of environmental protection barriers in place. The nature of the produced particulate waste suspended within the atmosphere and its ease of transported make most conventional air treatment systems unsuitable. The threat of such a contamination risk requires the selected solution to be capable of treating atmosphere containing extremely high concentrations of liquid and solid particles. In order to make the treatment selection and development process possible these particulates to be characterised, in addition the extent of contamination needs to be understood. The study will focus principally upon the water droplets produced from the high pressure jetting operations and there evolution through the decontamination environment. This is due to the difficulties such high atmospheric liquid water content poses for atmospheric treatment.

The process of high pressure water jetting has not currently been implemented within the nuclear industry on a wide scale with the typical water jets currently in use being lower pressured units (<300 Bar) this makes the estimation of the effects of droplets difficult to estimate (12). The consequences of this decontamination may be detrimental to the current containment practice used within such facilities. When implemented into a fully contained facility the performance of such systems may not be of sufficient reliability in order to guarantee environmental protection. This lack of a current understanding leaves the secondary contamination pathways identified as an unknown in terms of containment security and leaves environmental protection in question. To fully implement water jetting as a wildly accepted method of decontamination it is necessary to fully investigate the secondary contamination pathways identified and ensure suitable protection barriers are reasonably developed for the operations being conducted.

Atmospheric Protection Barrier

There is a need for facilities that are considering conducting mechanical decontamination operations such as high pressure water jetting to implement air treatment systems (17). These systems act as an environmental protection barrier preventing radiation escape. Such systems must be appropriately designed to handle large volumes of aerosols and high water droplet concentrations. Such systems act to prevent radionuclide escape as well as remove water droplets responsible for impairing the vision of operators conducting jetting operations and provide a negative pressure within the decontamination chamber preventing radionuclide escape (18). Air treatment systems within nuclear active sites are typically fitted with cellulose filter banks tasked with removing radioactive particles which are produced during decontamination operations within nuclear sites (19). However, it is not yet known if such systems are appropriate protection barriers within water jetting facilities. Degradation rates of the industry standard nuclear grade High-efficiency particulate arrestance filter (HEPAhave only undergone testing and certification in environments with relative humidity <70%. This must be taken into consideration as such filters are wide spread within the global nuclear industry as the main staple of atmospheric treatment (20). The adverse conditions present within the decontamination environment such as high humidity and heavy particle loading are thought to be responsible for increased degradation rates within HEPA filters (21).

It is widely accepted that over time air treatment systems degrade if they are operated without regular maintenance. This can lead to an increase in the risk off potential failure for filters (22). The processes leading to such damage are dependent upon the operational setting they have been selected to treat. High particle loading of aerosols and large concentrations of water droplets can leaded to decreased system performance and eventual failure (23). In this decontamination setting it assumed that high water droplet concentration and relative humidity are the main factors responsible for filter degradation (21). It is the aim of this study to implement a number of measurement techniques to identify the conditions present within decontamination facilities operating water jets as a treatment method.

Atmospheric Characterisation

To evaluate the exact conditions that are produced during high pressure water jetting surface decontamination, it is necessary to perform a detailed characterisation study of the resulting particulates emanated into the atmosphere. The main focus of the investigation will be into the large concentrations of water droplets and high relative humidity that is created during operations within the sealed decontamination cell that is used. When a high pressured water jet nozzle is focused upon a target surface the high energy impaction results in the production of large concentrations of droplets. Due to the operational specifications of the current filtration components requiring an operating RH of <70% and the actual conditions within jetting facilities being in excess of 70-100% RH it is assumed that damage will occur within such systems.

To carry out this investigation a range of atmospheric instruments will be implemented to determine the conditions present within the confined environments typical of such operational facilities (24). These instruments operate by the detection of forward-scattering caused by the presence of a particle passing through a region of a laser beam and the use of the Phase Doppler effect within a particle analyser (25). The instruments will be implemented in order to first determine the conditions produced when a water jet is placed into a chamber and operated and in addition to characterise the resulting changes operating an atmospheric treatment system will pose upon such an environment. The key aim of such instruments is to determine the droplet concentration, size distribution and the liquid water content of the atmosphere. Such information will be useful in estimating the potential for filter damage and the extent of the distance of travel of the produced droplets.

METHODS

Experimental Setup

To establish the conditions created within a water jetting decontamination chamber a 200 Bar water jetting unit was placed within a 7.85 m^3 stainless steel chamber. The water jet nozzle must be focused on an impaction target plate in order to simulate the decontamination process and the effect this will have upon the produced water droplets, the distance from nozzle to impaction plate will be

set at a specific distance known as the stand-off distance to evaluate the effect this may have upon droplet size distribution and concentration. The chamber will be fitted with a simulation air treatment system, this will consist of an electric fan unit providing the ventilation to the chamber, a nuclear grade HEPA filter with a flow rate of 70 L/sec and an operating range of 80% relative humidity. The air treatment components are joined with flexible ducting emanating from a camber access port this allows for the atmosphere contained within the chamber which contains water droplets and aerosols to be removed passing through the simulation air treatment system. Operations will be simulated both with the air treatment simulation in effect and without, this will enable the assessment of the consequence water jetting and the air treatment system have when operated in unison.
A number of instruments will be placed within the simulation chamber to assess the droplet characteristics. They shall be set at specific sampling locations in both ventilated and unventilated simulations and when the air treatment system is in use the instruments will be placed within it in order to assess the progression of water droplets within the system.

Droplet Characterisation, Investigation of Impacted and Un-Impacted Droplets Within a Decontamination Chamber
To ensure a base understanding of the interactions between the pressurised water jets and the surrounding atmosphere it is necessary to conduct an initial characterisation phase of the droplets produced during operations. This experiment will collect data related to the spray plume produced by a high pressure water jetting unit functioning within a confined decontamination chamber. The water jet will be operated while being focused upon an impaction target plate, this action will simulate the surface decontamination method. The experiment will also be conducted without the impaction target in place, leaving the water jet uninterrupted. Conducting both conditions will enable the effects of surface decontamination upon the atmospheric condition within the chamber to be assessed, highlighting differences in the extent of droplet progression within the chamber and variation within the droplet size range.

The experiment will first replicate Water jetting operations within a chamber with a static atmosphere present within the chamber. This phase of experimentation will allow the instruments selected to identify the base conditions produced and focus upon the droplets present within the chamber. The droplet size distribution, atmospheric liquid water content and total droplet concentrations data will be collected from the confined atmosphere. The identification of these parameters will provide a detailed background into the droplet production associated with water jetting operations. Using multiple sampling locations within the chamber at alternating heights will allow for the extent of the droplet plume to be determined and analysed. Three sampling locations will be used at 0.5 meters, 5 meters and 8 meters during a sampling duration of 5 minutes. The instruments will collect the required data both during spray operations and once water jetting has ceased, this is to characterise the produced spray plume and to monitor its decay.

The data obtained from these simulations will be placed within a graphical output representing the relation between liquid water content, droplet concentration and mode volume diameter. These parameters will be compared across all three measurement stations for the five minute tests, each experimental run will be conducted in triplicate to ensure reliability. The graphical outputs will provide an insight into the observable differences associated with water jet surface treatment appose to the un-impacted operation of such a jet in a confined chamber.

Simulation HEPA Air Filtration Assessment With Stand-off Distance Variation Experiment

To determine the effects water jetting operations may pose to the atmospheric treatment system in place at the Sellafield site it is necessary to undertake a scaled study of such a unit. The replica air treatment system will consist of an air extraction unit, HEPA filter and flexible ventilation ducting. This system will remove the atmosphere from the decontamination chamber and pass it through the HEPA filter insert. The Filter insert will then remove particles contained within the extracted air, this will cause loading of the filter material with droplets and aerosols as the test progress. The experiment will aim to assess the effects such treatment may have upon droplet dispersion and evolution within the decontamination environment as well as identifying the droplets removed by the filtration system itself. It is hoped that this process will also identify any consequent damage caused to the filter element of the system, such damage is thought to occur by filter exposure to high humidity and heavy droplet loaded atmosphere being passed through the HEPA filter. The experimental set up will aim to reproduce the operational processes of water jetting surface decontamination as closely as possible to observe such effects, this will require the variation of stand-off distance from the jetting nozzle to the contaminated surface. Data will be collected by placing instruments within the filtration system, these will monitor a number of variables as simulations are conducted. These will include: humidity, water droplet concentration, droplet distribution and pressure drop across the filter unit. Utilising these variables estimations of filter performance during operations are effected as a result of water jetting operations. In addition, aspects of the process contribute to filter degradation and therefore reduced air treatment efficiency can be highlighted. The identification of factors effecting filter performance and potential damage mechanisms is of great interest within the study, as such effects may contribute to the breach of radiation containment from decontamination facilities. The experiments will also evaluate the suitability of HEPA cellulose filters as an effective atmospheric treatment barrier and provide recommendations as to their suitability.

Conducting these experiments into the conditions produced during water jetting decontamination will allow a comparison to be drawn against those experienced when an air filtration treatment unit is operational. This aspect of the study will aim to identify the droplets most susceptible to filter uptake. A detailed overview can then be made of how the use of an air treatment system impacts upon the transportation and behaviours of water droplets produced within the decontamination chamber. The identification of droplets responsible for filter interactions will aid in the determination of those responsible for filter interactions and damage. The identification of such droplets will allow the damage mechanisms to be estimated with respect to the filter degradation. The results obtained will used to develop larger scale data collection from operational facilities as the Sellafield site.

Droplet Characterisation Investigation Results

The experiment conducted focused upon the comparison of water jetting plumes within a confined chamber. Two conditions were compared, the first where the high pressure jet was focused upon an impaction plate simulating the surface decontamination process and the second was an un-impacted jet emanating into the chamber. Data was recorded at 3 separate localities within the chamber differing in their height within the chamber, with the aim of recording the progression of the spray plume. Data was gathered principally with the CDP probe due to the reliability of measurements at the estimated droplet concentration and liquid water content. The results of the test conducting have been displayed in graphical format, indicating the relationship between liquid water content, droplet concentration and the median droplet diameter.

The results from the level 1 sampling point differ greatly between the two conditions of impacted and un-impacted jet plumes. Firstly, the droplet concentration recorded at level one was within the range of 0-5000 droplets per cm^3 for the un-impacted conditions whereas concentrations ranged from 0-10,000 droplets per cm^3 in the impacted spray conditions. Liquid water content peaked at 2.5 g/m^3 for the un-impacted conditions compared to 4 g/m^3 during the impacted spray conditions. The MVD range for the un-impacted test ranges from 12-20 µm whereas the MVD range experienced within the impacted tests was 5-25 µm.

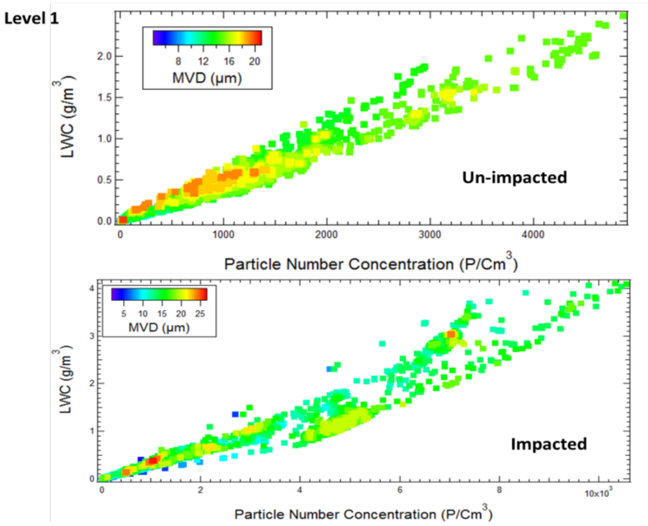

Figure 1, graphical results from the level 1 sampling location. A comparison of LWC to droplet concentration with droplet median velocity represented using a colour intensity scale.

The experimental results obtained from the level 2 sampling location indicated variations in the data compared to the 1st level sampling location. For the un-impacted conditions particle number concentration saw a reduction in the detected range with droplets being between 0-1400 per cm^3 whereas the impacted conditions experienced particles in the range of 0-6500 per cm^3, droplet concentrations see a reduction in this sampling zone when compared to the 1st level sampling port concentrations. The liquid water content for the un-impacted and impacted simulations ranged from 0 to 3.5 g/m^3, the impacted conditions however show a relationship between increased droplet concentration and LWC whereas the majority of the spray plume detected in the un-impacted conditions fell between 0.5g/m^3 and 1.5g/m^3 and at concentrations of 800-1400 per cm^3. The Median volume diameter for the two conditions was determined to be between 11µ and 24µm for the un-impacted conditions and 10µm to 18µm for the impacted conditions.

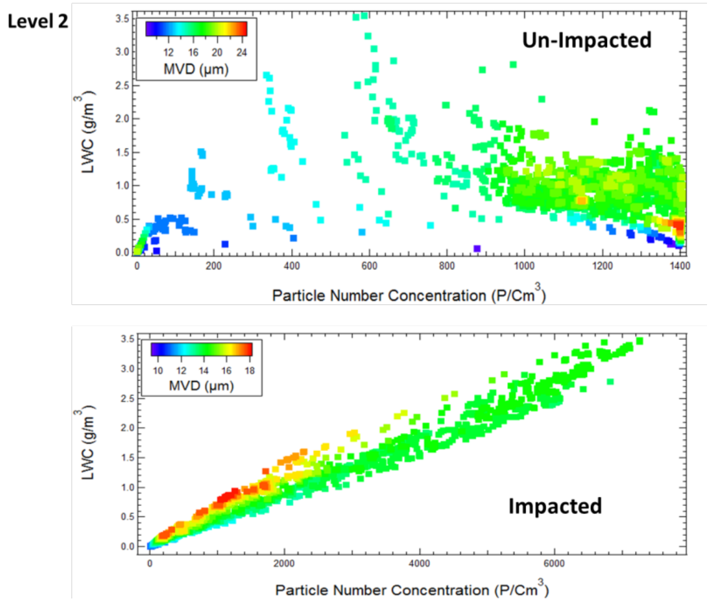

Figure 2, graphical results from the 2nd level sampling point. A comparison of LWC and droplet concentration with the droplet median volume diameter displayed with a colour intensity axis.

The results obtained from the level 3 sampling location show the droplet characteristics as their furthest extent from the jetting nozzle, the data can give an insight into the evolution of droplets as they progress through the chamber. The droplet concentrations at sampling point 3 indicated an increase when compared to sampling level 2, for the un-impacted conditions the concentrations ranged from 0-2500 per cm^3 and 0-10,000 per cm^3 for the impacted conditions. The liquid water content measured at this sampling point ranged from 0-1.2 $g/m3^3$ during the un-impacted conditions and 0-7 g/m^3 for the impacted spray conditions. Droplets range in size from 4-16 µm for the un-impacted conditions and 10-16 µm range for the impacted test conditions.

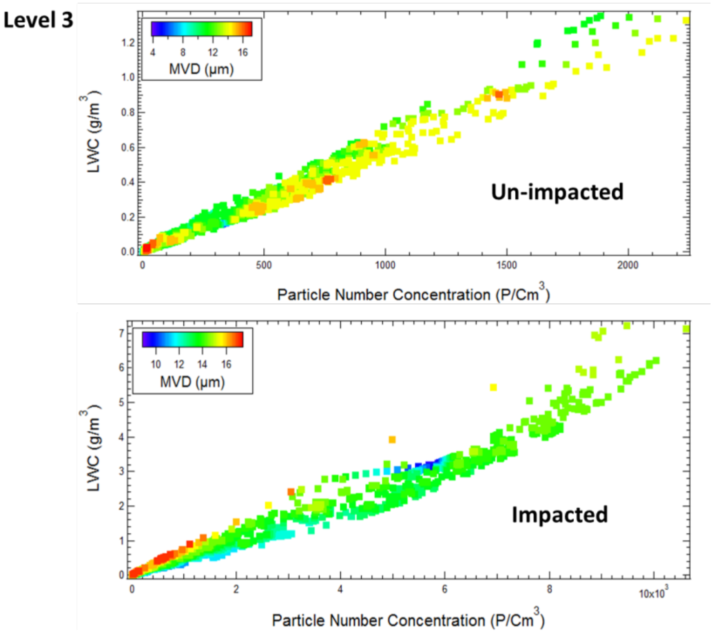

Figure 3 Results of obtained from the CDP located at the level 3 sampling location showing the comparison between LWC and droplet concentration, with the droplet median volume diameter displayed as a colour intensity axis on the graph.

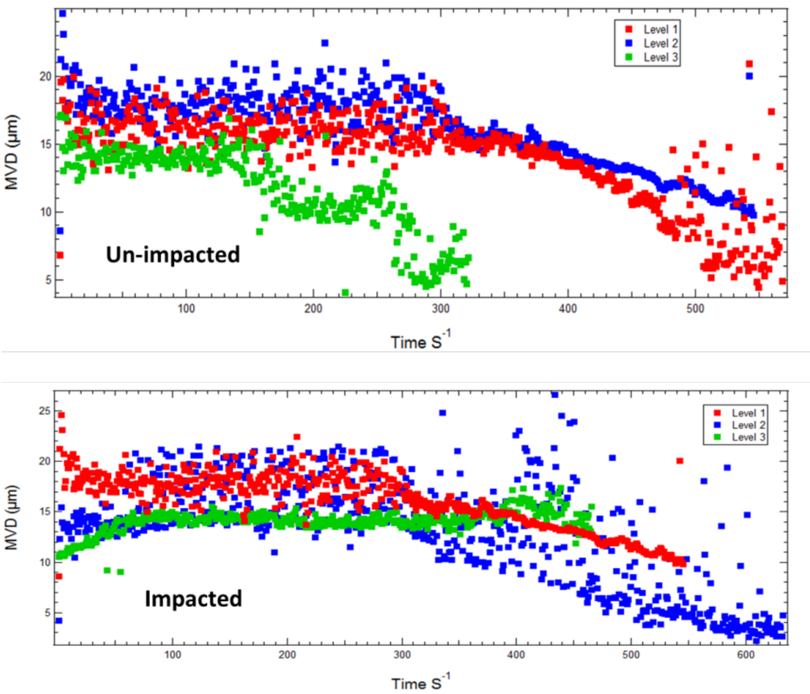

Figure 4 The changes in MVD over time during both impacted and un-impacted test conditions, during and after water jetting has been conducted.

To determine the droplet sizes recorded and how these change over time during and after a spray test event the MVD from each level and condition were compared against one and other. It was apparent that during the jetting phase of each test droplet MVD is at its highest with the largest droplets being recorded during this phase of the experiment in both the impacted and un-impacted conditions, however once the jetting has ceased a steady reduction in the MVD is observed until no more droplets are recorded.

HEPA Filter Simulation Results

To establish the effects water jetting operations have upon the standard air filtrations systems in place at the Sellafield site a scaled simulation was conducted. This scaled simulation implemented an industry standard nuclear grade HEPA filter, air extraction unit and a high pressure water jet. The experiments focused upon the progression of water droplets through the filtration system and the monitoring of filter droplet break-through. The stand-off distance of the water jet to the impaction plate was varied in order to observe the variations surface decontamination techniques may have upon the droplets produced and their subsequent damage to the filter media.

The results obtained by the CDP probe placed before the HEPA filter indicated a large variation than the results produced during the previous investigation which focused on impaction and un-impacted jetting conditions without the implementation of an air filtration system. During the air treatment simulations tests were conducted for 1, 5 and 10 minute jetting durations. The stand-off distance was varied between 4cm and 2cm from the target impaction plate, in order to assess the effect of procedural variance within the decontamination method.

The results displayed in figure 5 indicate a large variation in the produced conditions between the two spray conditions. It can be seen that much lower LWC and droplet concentrations are observed within the 2 cm stand-off distance test with concentrations observed between 0-14 droplets per cm^3 and LWC ranging from 0-0.16 g/m^3. When compared to the data recorded during the 4cm stand-off distance tests there is a significant increase in the droplet concentration range of 0-850 droplets per cm^3 and a liquid water content range of 0-3 g/m^3.

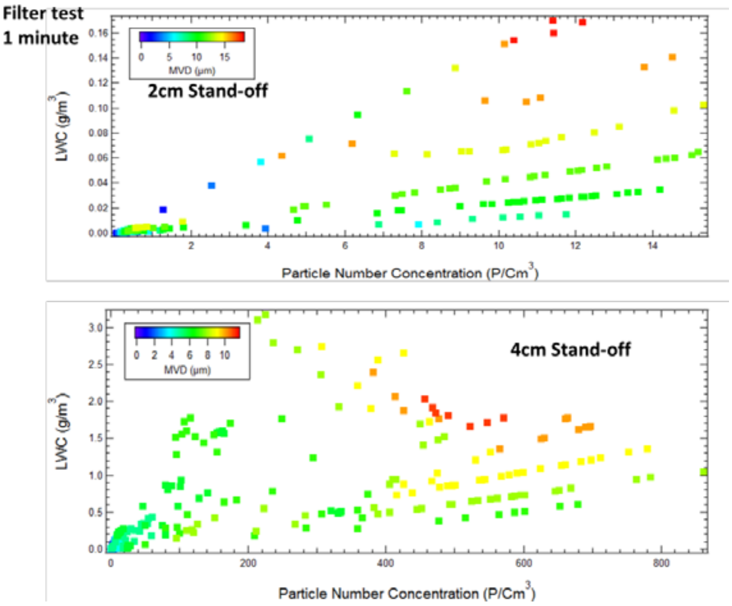

Figure 5 one minute jetting duration test CDP probe results, comparing LWC against droplet concentration with MVD indicated as a colour intensity scale.

The results obtained from the five minute jetting duration tests indicated a variation in the data obtained at the CDP sampling location when compared to the other testing durations. During the 2 cm stand-off distance tests a LWC range of 0 to 2.5 g/m^3 was detected and droplet concentrations ranging from 0-450 particles per cm^3 were recorded. The median volume diameter of the detected particles ranged from 4 to 16 µm in the 2 cm stand-off test. The data obtained for the 4 cm stand-off test indicated an increase in the LWC range when compared to the 1 minute spray duration test to 0-50 g/m^3 and an increase in the particle number concentration detected range to 0-1600 particles per cm^3. The median volume diameter range recorded during this test fell between 0 and 13 µm with the majority of recordings falling within 8-13 µm.

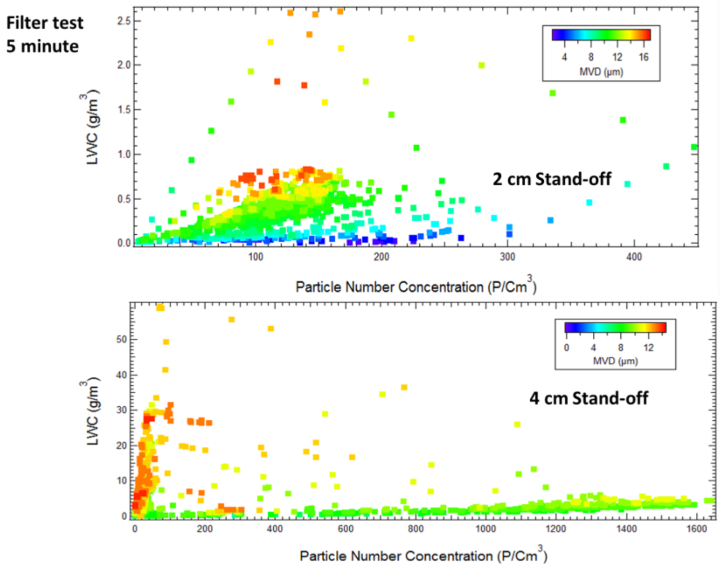

Figure 8 Five minute jetting duration test CDP probe results, comparing LWC against droplet concentration with MVD indicated as a colour intensity scale.

The 10 minute spray duration tests produced variable results when compared to the lower duration test runs. The data obtained from the 2 cm stand-off conditions indicated an increase in the droplet concentration range to 0-700 particles per cm^3 with the most frequent recorded concentrations falling within the 200-450 particles per cm^3 range. The recorded LWC during the test also saw an increase in the range detected to 0-300 g/m^3, however the majority of samplings fell below the 200 g/m^3. The median volume diameter range however remained similar, with droplets falling within the 0-12 µm size range. The results from the 4 cm stand-off test show a variation in the collected data when compared to those obtained during the 5 and 1 minute simulations. The LWC indicated an increase in the detected range to 0-550 g/m^{3}and a reduction in the range detected in the particle number concentration to 0-750 particles per cm^3. The median volume diameter range has also shifted to 4-14 µm indicating an increase in the overall particle size range.

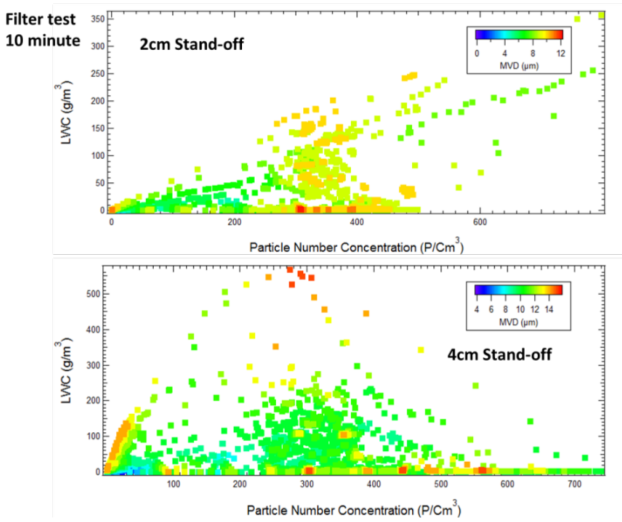

Figure 9 The ten minute jetting duration test CDP probe results, comparing LWC against droplet concentration with MVD indicated as a colour intensity scale.

Droplet Characterisation Investigation Discussion

The results obtained from the 3 sampling levels within the chamber gave a detailed interpretation towards the profile of the produced spray plume experienced both when jetting is operated as a surface decontamination measure and the un-interrupted jetting plume being released within the chamber. Both conditions are of importance with respect to the operating procedures implemented at the Sellafield site, this is due to the human lead nature of the operation, where the water jet maybe released without the nozzle being fixed upon the target. The aim of this investigation was to characterise the conditions produced during surface decontamination, the results were successfully obtained using the CDP probe.

The droplet concentrations recorded at each level for the un-impacted water jetting showed a general decrease as the plume passed through sampling locations 1,2 and 3 this indicates that as distance is increased from the jetting nozzle under un-impacted conditions it can be expected that the total concentration of droplets present will reduce. However, a lower concentration range was detected on the 2nd level sampling station, with the vast majority of detected particles being at the higher end of this range 900-1400 per cm^3 this can be clearly observed in the un-impacted graph in figure 2. When the concentrations of the un-impacted conditions are compared to those obtained for the impacted conditions it is clear to see that there is an apparent difference between the results recorded for the two conditions. The concentration range experienced during un-impacted spraying is greatly wider than during the un-impacted tests at all 3 sampling localities. However, the reduction in concentration range at the 2nd sampling level is also observed during the impacted test conditions with particles falling within the range of 0-6500 per cm^3.

The results obtained from the 3 sampling levels with regards to the liquid water content of the produced spray plumes indicated that LWC shows a gradual increase as the plume travels through the test chamber. The increase observed in droplet concentrations at all 3 sampling level correlates with this recorded in

LWC throughout the majority of the test conditions. Only during the un-impacted level 2 simulations does this coalition not hold true, during this test a wide range of liquid water contents are observed within the high droplet concentration range of the test with the majority of droplets being recorded within 0.5-1.5 g/m^3 range.

The median volume diameter recorded for the tests indicate a general decrease in droplet size as spray plume progresses through the chamber atmosphere. This trend is evident through both the un-impacted and impacted test conditions used and can be observed at all 3 levels of sampling. The reduction in droplet size can be attributed to the specific droplet velocity and the droplets settling rate held by the larger particles which do not reach the 3rd level of sampling. Typically, the largest droplets are observed when there is a low droplet concentration and LWC, these conditions are usually observed during the initial stages of the 5 minute test. Droplet MVD reduces as time elapses during the test simulations across both conditions. The recorded MVD data indicates that after the 5 minute jetting phase ends there is a reduction in the size of recorded particles within the sampling zones, the reduction in MVD as time progresses is most notable within the un-impacted test conditions.

HEPA Filter Simulation Discussion

By comparing the two stand-off distances and time variants it is possible to make assumptions concerning the number of droplets available for filter interactions within the air filtration system used within the simulations. It is assumed a greater number of droplets will lead to greater amounts of operational degradation and filter damage. Filter damage is thought to be caused as a result of increased pressure drop within the filter, droplet loading of the filter media and media saturation as a result of high humidity conditions. The data obtained during the 2 cm stand-off distance test simulations showed large variations within the concentrations of droplets produced by the high pressure water jetting and variance within the recorded LWC across the 3 time durations selected. Initial test conditions focused upon spray duration of 1 minute, at this spray intensity is clear to see that relatively low concentrations of droplets are detected by the CDP probe and thus the liquid water content recorded by the probe is also in the lower range of values experienced within the tests. The median volume diameter however remains within a similar range throughout the 3 time intensity's. The limited concentration of droplets detected during the 1 minute spray tests and as consequence the lower LWC can be attributed to the volume of the decontamination chamber and the time required for the still atmosphere to become loaded with the droplets produced by the high pressure water jet. Only once the droplets are distributed within the chamber atmosphere will they become detectable within the air treatment system withdrawing the chamber atmosphere. The MVD however remains within a closely correlating range when compared to the other test durations as this variable is controlled by jet velocity and stand-off distance which remained unchanged throughout the simulations. As the spray duration is increased to 5 minutes there is a sharp rise in both the detected particle concentration and the LWC present within the air treatment inlet. This increase can be attributed towards the ability of the chamber atmosphere to undergo saturation and mixing with regards to the produced water droplet, the MVD remained within the expected range however. As spray duration was increased to 10 minutes a large increased in the LWC detected was observed within the air treatment inlet along with a much more marginal rise in particle concentration. This increase in LWC without a correlating increase in particle concentration could be attributed to droplets being produced with a diameter too small to be detected by the CDP instrument.

The results obtained during the 4 cm stand-off distance tests indicate a clear variance when compared to those obtained during the 2 cm Sand-off distance tests. The initial testing period consisting of 1 minute of water jetting at an impaction surface, these produced conditions with a greater concentration of droplets and higher LWC than those recorded in the 2cm test. In addition to this a reduction in the range of MVD was identified, this result was unexpected as a greater stand-off distance was thought to produce droplets with a larger diameter. The variations in droplet concentration and LWC are thought to be attributed towards the difference in stand-off distance, the closer the jetting nozzle is placed to the impaction target the more focused the water jet becomes. This means that initial droplet concentrations are lower the closer the jetting nozzle is placed to the target surface due to the reduced availability of droplets for atmospheric mixing.

During the 5 minute jetting simulations with a 4 cm stand-off distance the results obtained showed a great difference when they are compared to those produced during the 2 cm stand-off distance simulations. Firstly, the peak droplet concentration from all the tests conducted during the experimental run was recorded during these conditions, with the higher concentrations occurring within lower LWC and lower concentrations occurring within the higher LWC range. The recorded LWC during this test indicated that lower concentrations of droplets occur in conjunction with higher LWC this could be attributed to the whole range of water droplets not being detected by the CDP probe. The median volume diameter for the test indicated a reduction in the droplet size range, with the larger droplets being detected at the greater LWC's.
The water jet simulations consisting of a 10 minute jetting duration and a 4 cm stand-off distance provided results with a large variance in the detected LWC when compared to other simulations with a set stand-off of 4 cm, with a 10 fold increase in the detected LWC within the air filtration system inlet when compared to the five minute duration test. However, the droplet concentration detected during the 10 minute simulations saw a reduction in the concentration range experienced within the test when compared to the 5 minute duration. The extremely high LWC detected within the air filtration inlet during the simulations indicates the worst case scenario for water jetting operations as 10 minutes of continuous decontamination operations is not a typical operational procedure conduced within the Sellafield site. The finding of the simulations did not run concurrent with the previously predicted outcome of the experiment was that both higher particle concentrations and LWC would be detected at a lower stand-off distance to the target surface, however during these simulations the reverse is observed with the 4 cm stand-off position producing greater droplet concentrations and LWC's. It was assumed that a lower stand-off distance would cause the droplets to impact at a higher velocity resulting in the break-up of droplets thus leading to higher droplet concentrations within the air treatment inlet. Utilising the results obtained during previous a pervious experimental trail the results can be seen to hold true as during this trail a stand-off distance of 6 cm was implemented which produced much greater concentrations of droplets within the decontamination chamber with lower spray duration. The median

volume diameter of the droplets detected fell within the similar range which has been observed within all test simulations conducted within the study indicating the stand-off distance selected influences droplet size to a lower extent at the tested droplet velocities, text changes in format here:
However, the range of the CDP probe cannot provide details to any produced droplets below the target range.

CONCLUSION

The results obtained during the water jetting characterisation phase of the study indicate a large variation between the droplets produced by the two jetting conditions. Higher droplet concentrations are observed during the impacted spray testing, within a lower range recorded in the droplet size distribution. This variation within the conditions is of importance with regards to the use of an air treatment system to remove the droplets produced by such a process. The data indicates that a system focusing upon droplets with a diameter lower than 50 µm would be most appropriate with regards to the conditions observed during the simulating water jetting tests. The high concentration of water droplets and large LWC of the produced atmosphere are of great concern with respect to current air treatment systems due to their requirement to be operated below 90% relative humidity.

The study highlighted further areas of investigation required to establish the extent of droplet interactions with the air treatment systems utilised to contain the process. After identifying the nature of the produced droplets it is necessary to undertake a scaled simulation upon replica treatment methods implemented with the Sellafield water jetting set-up. Focusing on the potential damage mechanisms associated with the high droplet loaded atmosphere and the suitability of current methods of air treatment to ensure that environmental protection barriers are maintained.

To address the short comings of the droplet characterisation, study the HEPA filter assessment aimed to indicate the operational implications of such treatment methods. The results taken from the filtration simulation study indicate that the main factors affected by stand-off distance within a confined spray chamber are LWC and droplet concentration. The CDP probe placed within the air filtration inlet provided a detailed insight into the conditions experienced when high pressure water jetting operations are conducted. The increase in the severity of these factors can also be linked to the operational duration of the surface treatment methods, with longer treatment regimens contributing towards much greater LWCs and droplet concentrations within the air filtration system. The surprising results from the analysis conducted are the little increase observed in the median volume diameter of the droplets being produced. It was expected initially that droplet size would decrease with reduced stand-off distance however the experiments has suggested that at the selected water pressures and flow rates that this is not the case and given the two stand-off distances implemented within the tests little variation is detected between the droplet diameters produced by each condition. The implications of the results obtained from the conducted simulations with regards to the security of current air filtrations techniques is that damage to such systems will be increased by increased duration of operations, inaccurate and misplaced operations of the water jetting nozzle and the proximity of operations to air treatment systems. This damage is assumed to increase with greater LWC and droplet concentrations within the atmosphere extracted from the decontamination chamber. The identification of droplet concentrations, size and LWC at the filtration inlet can enable estimations to be made upon the conditions interacting with the air filtration unit contained within the system.

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